



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>







COURSE OF SIX LECTURES
ON THE
VARIOUS FORCES OF MATTER,
AND
THEIR RELATIONS TO EACH OTHER.

BY
MICHAEL FARADAY, D.C.L., F.R.S.,
FULLERIAN PROFESSOR OF CHEMISTRY, ROYAL INSTITUTION.

*Delivered before a JUVENILE AUDITORY at the ROYAL INSTITUTION
of GREAT BRITAIN during the Christmas Holidays of 1859-60.*

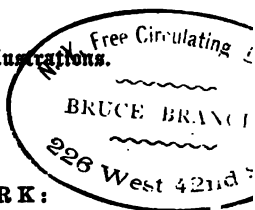
EDITED BY WILLIAM CROOKES, F.C.S.

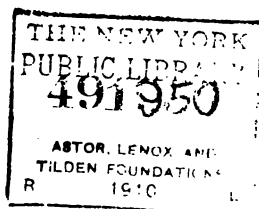
With Numerous Illustrations.

NEW YORK:

HARPER & BROTHERS, PUBLISHERS,
FRANKLIN SQUARE

1868.





76
2195

530
F-14

P R E F A C E.

WHICH was first, Matter or Force? If we think on this question, we shall find that we are unable to conceive of matter without force, or force without matter. When God created the elements of which the earth is composed, He created certain wondrous forces, which are set free and become evident when matter acts on matter. All these forces, with many differences, have much in common, and if one is set free it will immediately endeavor to free its companions. Thus heat will enable us to eliminate light, electricity, magnetism, and chemical action; chemical action will educe light, electricity, and heat; in this way we find that all the forces in nature tend to form mutually dependent systems, and as the motion of one star affects another, so force in action liberates and renders evident forces previously tranquil.

We say tranquil, and yet the word is almost

without meaning in the Cosmos; where do we find tranquillity? The sea, the seat of animal, vegetable, and mineral changes, is at war with the earth, and the air lends itself to the strife. The globe, the scene of perpetual intestine change, is, as a mass, acting on, and acted on by the other planets of our system, and the very system itself is changing its place in space under the influence of a known force springing from an unknown centre.

For many years past the English public have had the privilege of listening to the discourses and speculations of Professor Faraday, at the Royal Institution, on Matter and Forces, and it is not too much to say that no lecturer on Physical Science since the time of Sir Humphrey Davy has been listened to with more delight. The pleasure which all derive from the expositions of Faraday is of a somewhat different kind to that produced by any other philosopher whose lectures we have ever attended. It is partially derived from his extreme dexterity as an operator—with him we have no chance of apologies for an unsuccessful

experiment, no hanging fire in the midst of a series of brilliant demonstrations, producing that depressing tendency akin to the pain felt by an audience at a false note from a vocalist. All is a sparkling stream of eloquence and experimental illustration. We defy a chemist who loves his science, no matter how often he may have repeated an experiment, to feel uninterested when seeing it done by Faraday.

The present publication presents one or two points of interest. In the first place, the Lectures were especially intended for young persons, and are therefore as free as possible from technicalities; and, in the second place, they are printed as they were spoken, *verbatim et literatim*. A careful and skillful reporter took them down, and the manuscript, as deciphered from his notes, was subsequently corrected by the editor as regards any scientific points which were not clear to the short-hand writer; hence all that is different arises solely from the impossibility, alas! of conveying the manner as well as the matter of the lecturer.

The interest which was felt in those numbers of the CHEMICAL NEWS in which the lectures

appeared was so great that the republication of them in a separate form was considered to be almost a duty to those young lovers of science to whom a purely chemical journal with its inevitable technicalities would be a sealed book. May the readers of these Lectures derive one tenth of the pleasure and instruction from their perusal which they gave to those who had the happiness of hearing them !

W. C.

CONTENTS.

LECTURE I.	
	PAGE
THE FORCE OF GRAVITATION.....	13

LECTURE II.	
GRAVITY—COHESION	44

LECTURE III.	
COHESION—CHEMICAL AFFINITY	72

LECTURE IV.	
CHEMICAL AFFINITY—HEAT.....	98

LECTURE V.	
MAGNETISM—ELECTRICITY	120

LECTURE VI.	
THE CORRELATION OF THE PHYSICAL FORCES	144

LIGHT-HOUSE ILLUMINATION—THE ELECTRIC LIGHT....	171
NOTES.....	191



LECTURES
ON
THE PHYSICAL FORCES.

LECTURE I.

THE FORCE OF GRAVITATION.

IT grieves me much to think that I may have been a cause of disturbance to your Christmas arrangements⁽¹⁾, for nothing is more satisfactory to my mind than to perform what I undertake; but such things are not always left to our own power, and we must submit to circumstances as they are appointed. I will to-day do my best, and will ask you to bear with me if I am unable to give more than a few words; and, as a substitute, I will endeavor to make the *illustrations* of the sense I try to express as full as possible; and if we find by the end of this lecture that we may be justified

in continuing them, thinking that next week our power shall be greater, why then, with submission to you, we will take such course as you may think fit, either to go on or discontinue them; and although I now feel much weakened by the pressure of the illness (a mere cold) upon me, both in facility of expression and clearness of thought, I shall here claim, as I always have done on these occasions, the right of addressing myself to the younger members of the audience; and for this purpose, therefore, unfitted as it may seem for an elderly infirm man to do so, I will return to second childhood, and become, as it were, young again among the young.

Let us now consider, for a little while, how wonderfully we stand upon this world. Here it is we are born, bred, and live, and yet we view these things with an almost entire absence of wonder to ourselves respecting the way in which all this happens. So small, indeed, is our wonder, that we are never taken by surprise; and I do think that, to a young person of ten, fifteen, or twenty years of age, perhaps *the first sight* of a cataract or a mountain would

occasion him more surprise than he had ever felt concerning the means of his own existence; how he came here; how he lives; by what means he stands upright; and through what means he moves about from place to place. Hence, we come into this world, we live, and depart from it, without our thoughts being called specifically to consider how all this takes place; and were it not for the exertions of some few inquiring minds, who have looked *into* these things, and ascertained the very beautiful laws and conditions by which we *do* live and stand upon the earth, we should hardly be aware that there was any thing wonderful in it. These inquiries, which have occupied philosophers from the earliest days, when they first began to find out the laws by which we grow, and exist, and enjoy ourselves, up to the present time, have shown us that all this was effected in consequence of the existence of certain *forces*, or *abilities* to do things, or *powers*, that are so common that nothing can be more so; for nothing is commoner than the wonderful powers by which we are enabled to stand upright: they are essential to our existence every moment.

It is my purpose to-day to make you acquainted with some of these powers; not the vital ones, but some of the more elementary, and what we call *physical* powers; and, in the outset, what can I do to bring to your minds a notion of neither more nor less than that which I mean by the word *power* or *force*? Suppose I take this sheet of paper, and place it upright on one edge, resting against a support before me (as the roughest possible illustration of something to be disturbed), and suppose I then pull this piece of string which is attached to it. I pull the paper over. I have therefore brought into use a *power* of doing so—the *power* of my hand carried on through this string in a way which is very remarkable when we come to analyze it; and it is by means of these powers conjointly (for there are several powers here employed) that I pull the paper over. Again, if I give it a push upon the other side, I bring into play a *power*, but a very different exertion of power from the former; or, if I take now this bit of shell-lac [a stick of shell-lac about 12 inches long and $1\frac{1}{2}$ in diameter], and rub it with flannel, and hold it an inch or so

in front of the upper part of this upright sheet, the paper is immediately moved toward the shell-lac, and by now drawing the latter away, the paper falls over without having been touched by any thing. You see, in the first illustration I produced an effect than which nothing could be commoner; I pull it over now, not by means of that string or the pull of my hand, but by some action in this shell-lac. The shell-lac, therefore, has a *power* wherewith it acts upon the sheet of paper; and, as an illustration of the exercise of another kind of power, I might use gunpowder with which to throw it over.

Now I want you to endeavor to comprehend that when I am speaking of a *power* or *force*, I am speaking of that which I used just now to pull over this piece of paper. I will not embarrass you at present with the *name* of that power, but it is clear there was a *something* in the shell-lac which acted by attraction, and pulled the paper over; this, then, is one of those things which we call *power*, or *force*; and you will now be able to recognize it as such in whatever form I show it to you. We are not to

suppose that there are so very many different powers; on the contrary, it is wonderful to think how few are the powers by which all the phenomena of nature are governed. There is an illustration of another kind of power in that lamp; *there* is a power of heat—a power of doing something, but not the same power as that which pulled the paper over; and so, by degrees, we find that there are certain other powers (not many) in the various bodies around us; and thus, beginning with the simplest experiments of pushing and pulling, I shall gradually proceed to distinguish these powers one from the other, and compare the way in which they combine together. This world upon which we stand (and we have not much need to travel out of the world for illustrations of our subject; but the mind of man is not confined like the matter of his body, and thus he may and does travel outward, for wherever his sight can pierce, there his observations can penetrate) is pretty nearly a round globe, having its surface disposed in a manner of which this terrestrial globe by my side is a rough model; so much is land and so much is water; and by looking at

it here we see in a sort of map or picture how the world is formed upon its surface. Then, when we come to examine farther, I refer you to this sectional diagram of the geological strata of the earth, in which there is a more elaborate view of what is beneath the surface of our globe. And, when we come to dig into or examine it (as man does for his own instruction and advantage, in a variety of ways), we see that it is made up of different kinds of matter, subject to a very few powers; and all disposed in this strange and wonderful way, which gives to man a history—and such a history—as to what there is in those veins, in those rocks, the ores, the water-springs, the atmosphere around, and all varieties of material substances, held together by means of *forces* in one great mass, 8000 miles in diameter, that the mind is overwhelmed in contemplation of the wonderful history related by these strata (some of which are fine and thin like sheets of paper), all formed in succession by the forces of which I have spoken.

I now shall try to help your attention to what I may say by directing, to-day, our thoughts to

water gravitating toward the earth. Now *here* [exhibiting a small piece of platinum⁽²⁾] is another thing which gravitates toward the earth as much as the whole of that water. See what a little there is of it; *that* little thing is heavier than so much water [placing the metal in opposite scales to the water]. What a wonderful thing it is to see that it requires so much water as *that* [a half-pint vessel full] to fall toward the earth, compared with the little mass of substance I have *here*! And again, if I take this metal [a bar of aluminium⁽³⁾ about eight times the bulk of the platinum], we find the water will balance that as well as it did the platinum; so that we get, even in the very outset, an example of what we want to understand by the words *forces* or *powers*.

I have spoken of water, and first of all of its property of falling downward: you know very well how the oceans surround the globe—how they fall round the surface, giving roundness to it, clothing it like a garment; but, besides that, there are other properties of water. *Here*, for instance, is some quicklime, and if I add some water to it, you will find another power

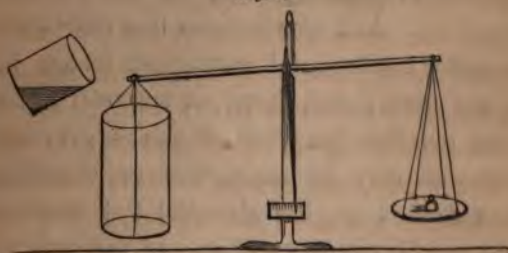
or property in the water.⁽⁴⁾ It is now very hot; it is steaming up; and I could perhaps light phosphorus or a lucifer-match with it. Now that could not happen without a *force* in the water to produce the result; but that force is entirely distinct from its power of falling to the earth. Again, here is another substance [some anhydrous sulphate of copper⁽⁵⁾] which will illustrate another kind of power. [The lecturer here poured some water over the white sulphate of copper, which immediately became blue, evolving considerable heat at the same time.] Here is the same water with a substance which heats nearly as much as the lime does, but see how differently. So great indeed is this heat in the case of lime, that it is sufficient sometimes (as you see here) to set wood on fire; and this explains what we have sometimes heard, of barges laden with quick-lime taking fire in the middle of the river, in consequence of this power of heat brought into play by a leakage of the water into the barge. You see how strangely different subjects for our consideration arise when we come to think over these various matters—the power of heat

understand that all bodies are attracted to the earth, or, to use a more learned term, *gravitate*. You will not mind my using this word, for when I say that this penny-piece *gravitates*, I mean nothing more nor less than that it falls toward the earth, and, if not intercepted, it would go on falling, falling, until it arrived at what we call the *centre of gravity* of the earth, which I will explain to you by-and-by.

I want you to understand that this property of gravitation is never lost; that every substance possesses it; that there is never any change in the quantity of it; and, first of all, I will take as illustration a piece of marble. Now this marble has weight, as you will see if I put it in these scales; it weighs the balance down, and if I take it off, the balance goes back again and resumes its equilibrium. I can decompose this marble and change it in the same manner as I can change ice into water and water into steam. I can convert a part of it into *its own* steam easily, and show you that this steam from the marble has the property of remaining in the same place at common temperatures, which *water-steam* has not. If I

add a little liquid to the marble and decompose it⁽⁶⁾, I get that which you see—[the lecturer here put several lumps of marble into a glass jar, and poured water and then acid over them; the carbonic acid immediately commenced to escape with considerable effervescence]—the appearance of boiling, which is only the separation of one part of the marble from another. Now this [marble] steam, and that [water] steam, and all other steams, *gravitate* just like any other substance does; they all are attracted the one toward the other, and all fall toward the earth, and what I want you to see is that *this* steam gravitates. I have here (*fig. 2*) a

Fig. 2.

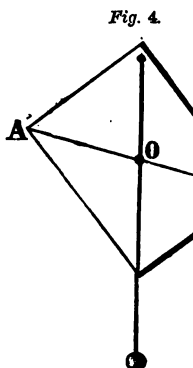
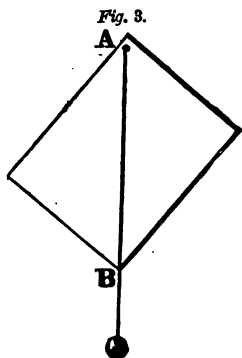


large vessel placed upon a balance, and the moment I pour this steam into it you see that the steam gravitates. Just watch the index,

and see whether it tilts over or not. [The lecturer here poured the carbonic acid out of the glass in which it was being generated into the vessel suspended on the balance, when the gravitation of the carbonic acid was at once apparent.] Look how it is going down. How pretty that is! I poured nothing in but the invisible steam, or vapor, or gas which came from the marble, but you see that part of the marble, although it has taken the shape of air, still gravitates as it did before. Now will it weigh down that bit of paper? [placing a piece of paper in the opposite scale.] Yes, more than that; it nearly weighs down this bit of paper [placing another piece of paper in]. And thus you see that *other* forms of matter besides solids and liquids tend to fall to the earth; and, therefore, you will accept from me the fact that *all* things gravitate, whatever may be their form or condition. Now *here* is another chemical test which is very readily applied. [Some of the carbonic acid was poured from one vessel into another, and its presence in the latter shown by introducing into it a lighted taper, which was im-

mediately extinguished.] You see from this result also that it gravitates. All these experiments show you that, tried by the balance, tried by pouring like water from one vessel to another, this steam, or vapor, or gas is, like all other things, attracted to the earth.

There is another point I want in the next place to draw your attention to. I have here a quantity of shot; each of these falls separately, and each has its own gravitating power, as you perceive when I let them fall loosely on a sheet of paper. If I put them into a bottle, I collect them together as one mass, and philosophers have discovered that there is a certain point in the middle of the whole collection of shots that may be considered as the *one point* in which all their gravitating power is centred, and that point they call the *centre of gravity*; it is not at all a bad name, and rather a short one—the centre of gravity. Now suppose I take a sheet of pasteboard, or any other thing easily dealt with, and run a bradawl through it at one corner, A (*fig. 3*), and Mr. Anderson hold that up in his hand before us, and I then take a piece of thread and an ivory ball, and hang



that upon the awl, then the centre of gravity of both the pasteboard and the ball and are as near as they can get to the centre of the earth; that is to say, the whole of the acting power of the earth is, as it were, centred at a single point of the cardboard, and this is exactly below the point of suspension. I have to do, therefore, is to draw a line corresponding with the string, and we find that the centre of gravity is somewhere on that line. But where? To find that out we have to do is to take another place for the awl (*fig. 4*), hang the plumb-line, and make the same experiment, and there [at the point where the two plumb-lines intersect] is the centre of gravity—there where the two

which I have traced cross each other; and if I take that pasteboard, and make a hole with the bradawl through it at that point, you will see that it will be supported in any position in which it may be placed. Now, knowing that, what do I do when I try to stand upon one leg? Do you not see that I push myself over to the left side, and quietly take up the right leg, and thus bring some central point in my body over this left leg? What is that point which I throw over? You will know at once that it is the *centre of gravity*—that point in me where the whole gravitating force of my body is centred, and which I thus bring in a line over my foot.

Here is a toy I happened to see the other day, which will, I think, serve to illustrate our subject very well. That toy *ought* to lie something in this manner (*fig. 5*), and would do so if it were uniform in substance; but you see it does not; it will get up again. And now philosophy comes to our aid; and I am perfectly sure, without looking inside the figure, that there is some arrangement by which the centre of gravity is at the lowest point when the im-

Fig. 8.

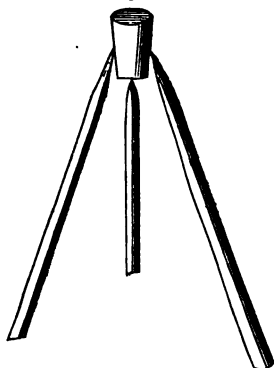
a table, a piece of stick, and a pail, and the proposition is, how can that pail be hung to the edge of this table? It is to be done, and can you at all anticipate what arrangement I shall make to enable me to succeed? Why this. I take a stick, and put it in the pail between the bottom and the horizontal piece of wood, and thus give it a stiff handle, and there it is; and, what is more, the more water I put into the pail, the better it will hang. It is very true that before I quite succeeded I had the misfortune to push the bottoms of several pails out; but here it is hanging firmly (*fig. 9*), and you now see how you can hang up the pail in the way which the conjuring books require.

Fig. 9.



Again, if you are really so inclined (and I do hope all of you are), you will find a great deal of philosophy in this [holding up a cork and a pointed thin stick about a foot long]. Do not refer to your toy-books, and say you have seen that before. Answer me rather, if I ask you, have you *understood* it before? It is an experiment which appeared very wonderful to me when I was a boy. I used to take a piece of cork (and I remember I thought at first that it was very important that it should be cut out in the shape of a man, but by degrees I got rid of that idea), and the problem was to balance it on the point of a stick. Now you will see I have only to place two sharp-pointed sticks one

Fig. 10.



on each side, and give it wings, thus, and you will find this beautiful condition fulfilled.

We come now to another point. All bodies, whether heavy or light, fall to the earth by this force which we call gravity. By observation, moreover, we see that bodies do not occupy the same time in falling; I think you will be able to see that this piece of paper and that ivory ball fall with different velocities to the table [dropping them]; and if, again, I take a feather and an ivory ball, and let them fall, you see they reach the table or earth at different times; that is to say, the ball falls faster than the feather. Now that should not be so, for all

bodies do fall equally fast to the earth. There are one or two beautiful points included in that statement. First of all, it is manifest that an ounce, or a pound, or a ton, or a thousand tons, all fall equally fast, no one faster than another: here are two balls of lead, a very light one and a very heavy one, and you perceive they both fall to the earth in the same time. Now if I were to put into a little bag a number of these balls sufficient to make up a bulk equal to the large one, they would also fall in the same time; for if an avalanche fall from the mountains, the rocks, snow, and ice, together falling toward the earth, fall with the same velocity, whatever be their size.

I can not take a better illustration of this than that of gold leaf, because it brings before us the reason of this apparent difference in the time of the fall. Here is a piece of gold leaf. Now if I take a lump of gold and this gold leaf, and let them fall through the air together, you see that the lump of gold—the sovereign or coin—will fall much faster than the gold leaf. But why? They are both gold, whether sovereign or gold leaf. Why should they not

fall to the earth with the same quickness *They would do so*, but that the air around our globe interferes very much where we have the piece of gold so extended and enlarged as to offer much obstruction on falling through it. I will, however, show you that gold leaf *does* fall as fast when the resistance of the air is excluded; for if I take a piece of gold leaf and hang it in the centre of a bottle, so that the gold, and the bottle, and the air within shall all have an equal chance of falling, then the gold leaf will fall as fast as any thing else. And if I suspend the bottle containing the gold leaf to a string, and set it oscillating like a pendulum, I may make it vibrate as hard as I please, and the gold leaf will not be disturbed, but will swing as steadily as a piece of iron would do; and I might even swing it round my head with any degree of force, and it would remain undisturbed. Or I can try another kind of experiment: if I raise the gold leaf in this way [pulling the bottle up to the ceiling of the theatre by means of a cord and pulley, and then suddenly letting it fall to within a few inches of the lecture table], and allow it

then to fall from the ceiling downward (I will put something beneath to catch it, supposing I should be *maladroit*), you will perceive that the gold leaf is not in the least disturbed. The resistance of the air having been avoided, the glass bottle and gold leaf all fall exactly in the same time.

Here is another illustration: I have hung a piece of gold leaf in the upper part of this long glass vessel, and I have the means, by a little arrangement at the top, of letting the gold leaf loose. Before we let it loose we will remove the air by means of an air-pump, and, while that is being done, let me show you another experiment of the same kind. Take a penny-piece, or a half crown, and a round piece of paper a trifle smaller in diameter than the coin, and try them side by side to see whether they fall at the same time [dropping them]. You see they do not—the penny-piece goes down first. But, now place this paper flat on the top of the coin, so that it shall not meet with any resistance from the air, and upon *then* dropping them you see they *do* both fall in the same time [exhibiting the effect]. I

LECTURE II.

GRAVITATION.—COHESION.

Do me the favor to pay me as much attention as you did at our last meeting, and I shall not repent of that which I have proposed to undertake. It will be impossible for us to consider the Laws of Nature, and what they effect, unless we now and then give our sole attention, so as to obtain a clear idea upon the subject. Give me now that attention; and then I trust we shall not part without our knowing something about those laws, and the manner in which they act. You recollect, upon the last occasion, I explained that all bodies attracted each other, and that this power we called *gravitation*. I told you that when we brought these two bodies [two equal-sized ivory balls suspended by threads] near together, they attracted each other, and that we might suppose that the whole power of this attraction was exerted between their respective centres

of gravity ; and, furthermore, you learned from me that if, instead of a small ball I took a larger one, like *that* [changing one of the balls for a much larger one], there was much more of this attraction exerted ; or, if I made this ball larger and larger, until, if it were possible, it became as large as the Earth itself—or I might take the Earth itself as the large ball—that *then* the attraction would become so powerful as to cause them to rush together in this manner [dropping the ivory ball]. You sit *there* upright, and I stand upright *here*, because we keep our centres of gravity properly balanced with respect to the earth ; and I need not tell you that on the other side of this world the people are standing and moving about with their feet toward our feet, in a reversed position as compared with us, and all by means of this power of gravitation to the centre of the earth.

I must not, however, leave the subject of gravitation without telling you something about its laws and regularity ; and, first, as regards its power with respect to the distance that bodies are apart. If I take one of these

ought first to be washed very clean, and dried; you will find to-morrow that we shall have a beautiful crystallization over the coke, making it exactly resemble a natural mineral.

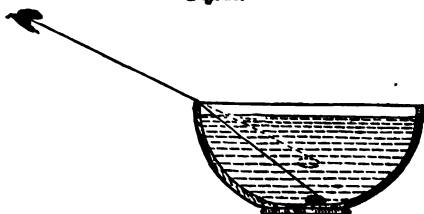
Now how curiously our ideas expand by watching these conditions of the attraction of cohesion! how many new phenomena it gives us beyond those of the attraction of gravitation! See how it gives us great strength. The things we deal with in building up the structures on the earth are of strength—we use iron, stone, and other things of great strength; and only think that all those structures you have about you—think of the *Great Eastern*, if you please, which is of such size and power as to be almost more than man can manage—are the result of this power of cohesion and attraction.

I have here a body in which I believe you will see a change taking place in its condition of cohesion at the moment it is made. It is at first yellow; it then becomes a fine crimson red. Just watch when I pour these two liquids together—both colorless as water. [The lecturer here mixed together solutions of perchloride

of mercury and iodide of potassium, when a yellow precipitate of biniodide of mercury fell down, which almost immediately became crimson red.] Now there is a substance which is very beautiful, but see how it is changing color. It was reddish-yellow at first, but it has now become red.⁽⁸⁾ I have previously prepared a little of this red substance, which you see formed in the liquid, and have put some of it upon paper [exhibiting several sheets of paper coated with scarlet biniodide of mercury⁽⁹⁾]. There it is—the same substance spread upon paper; and there, too, is the same substance; and here is some more of it [exhibiting a piece of paper as large as the other sheets, but having only very little red color on it, the greater part being yellow]—a *little* more of it, you will say. Do not be mistaken; there is as much upon the surface of one of these pieces of paper as upon the other. What you see yellow is the same thing as the red body, only the attraction of cohesion is in a certain degree changed; for I will take this red body, and apply heat to it (you may perhaps see a little smoke arise, but that is of no consequence), and if you look at

but we can not well find out how these forms become so, and I want you, therefore, to take a lesson in the way in which we use a ray of light for the purpose of seeing what is in the interior of bodies. Light is a thing which is, so to say, attracted by every substance that gravitates (and we do not know any thing that does not). All matter affects light more or less by what we may consider as a kind of attraction, and I have arranged (*fig. 18*) a very

Fig. 18.



simple experiment upon the floor of the room for the purpose of illustrating this. I have put into that basin a few things which those who are in the body of the theatre will not be able to see, and I am going to make use of this power which matter possesses of attracting a ray of light. If Mr. Anderson pours some *water, gently and steadily*, into the basin, the

water will attract the rays of light downward, and the piece of silver and the sealing-wax will appear to rise up into the sight of those who were before not high enough to see over the side of the basin to its bottom. [Mr. Anderson here poured water into the basin, and upon the lecturer asking whether any body could see the silver and sealing-wax, he was answered by a general affirmative.] Now I suppose that every body can see that they are not at all disturbed, while from the way they appear to have risen up you would imagine the bottom of the basin and the articles in it were two inches thick, although they are only one of our small silver dishes and a piece of sealing-wax which I have put there. The light which now goes to you from that piece of silver was obstructed by the edge of the basin when there was no water there, and you were unable to see any thing of it; but when we poured in water the rays were attracted down by it over the edge of the basin, and you were thus enabled to see the articles at the bottom.

I have shown you this experiment first, so *that you might* understand how glass attracts

with a pair of pliers.] You see, I now find no difficulty in bending this end about as I like, whereas I can not bend the cold part at all. And you know how the smith takes a piece of iron and heats it in order to render it soft for his purpose: he acts upon our principle of lessening the adhesion of the particles, although he is not exactly acquainted with the terms by which we express it.

And now we have another point to examine, and this water is again a very good substance to take as an illustration (as philosophers we call it all water, even though it be in the form of ice or steam). Why is this water hard? [pointing to a block of ice]; because the attraction of the particles to each other is sufficient to make them retain their places in opposition to force applied to it. But what happens when we make the ice warm? Why, in that case we diminish to such a large extent the power of attraction that the solid substance is destroyed altogether. Let me illustrate this: I will take a red-hot ball of iron [Mr. Anderson, by means of a pair of tongs, handed to the lecturer a red-hot ball of iron, about two inches in diameter],

because it will serve as a convenient source of heat [placing the red-hot iron in the centre of the block of ice]. You see I am now melting the ice where the iron touches it. You see the iron sinking into it; and while part of the solid water is becoming liquid, the heat of the ball is rapidly going off. A certain part of the water is actually rising in steam; the attraction of some of the particles is so much diminished that they can not even hold together in the liquid form, but escape as vapor. At the same time, you see I can not melt all this ice by the heat contained in this ball. In the course of a very short time I shall find it will have become quite cold.

Here is the water which we have produced by destroying some of the attraction which existed between the particles of the ice, for below a certain temperature the particles of water increase in their mutual attraction and become ice; and above a certain temperature the attraction decreases and the water becomes steam. And exactly the same thing happens with platinum, and nearly every substance in nature; *if the temperature is increased to a certain*

the case here, and all because salt has the power of lessening the attraction between the particles of ice. Here you see the tin dish is frozen to the board; I can even lift this little stool up by it.

This experiment can not, I think, fail to impress upon your minds the fact that whenever a solid body loses some of that force of attraction by means of which it remains solid, heat is absorbed; and if, on the other hand, we convert a liquid into a solid, *e. g.*, water into ice, a corresponding amount of heat is given out. I have an experiment showing this to be the case. Here (*fig. 21*) is a bulb, A, filled with

Fig. 21.



air, the tube from which dips into some colored liquid in the vessel B. And I dare say you

know that if I put my hand on the bulb A, and warm it, the colored liquid which is now standing in the tube at c will travel forward. Now we have discovered a means, by great care and research into the properties of various bodies, of preparing a solution of a salt⁽¹⁵⁾ which, if shaken or disturbed, will at once become a solid; and as I explained to you just now for what is true of water is true of every other liquid), by reason of its becoming solid heat is evolved, and I can make this evident to you by pouring it over this bulb; there! it is becoming solid; and look at the colored liquid, how it is being driven down the tube, and how it is bubbling out through the water at the end; and so we learn this beautiful law of our philosophy, that whenever we diminish the attraction of cohesion we absorb heat, and whenever we increase that attraction heat is evolved. This, then, is a great step in advance, for you have learned a great deal in addition to the mere circumstance that particles attract each other. But you must not now suppose that because they are liquid they have lost their attraction of cohesion; for here is the fluid mer-

cary, and if I pour it from one vessel into another, I find that it will form a stream from the bottle down to the glass—a continuous rod of fluid mercury, the particles of which have attraction sufficient to make them hold together all the way through the air down to the glass itself; and if I pour water quietly from a jug, I can cause it to run in a continuous stream in the same manner. Again: let me put a little water on this piece of plate glass, and then take another plate of glass and put it on the water; there! the upper plate is quite free to move, gliding about on the lower one from side to side; and yet, if I take hold of the upper plate and lift it up straight, the cohesion is so great that the lower one is held up by it. See how it runs about as I move the upper one, and this is all owing to the strong attraction of the particles of the water. Let me show you another experiment. If I take a little soap and water—not that the soap makes the particles of the water more adhesive one for the other, but it certainly has the power of continuing in a better manner the attraction *of the particles* (and let me advise you, when

about to experiment with soap-bubbles, to take care to have every thing clean and soapy). I will now blow a bubble, and that I may be able to talk and blow a bubble too, I will take a plate with a little of the soapsuds in it, and will just soap the edges of the pipe and blow a bubble on to the plate. Now there is our bubble. Why does it hold together in this manner? Why, because the water of which it is composed has an attraction of particle for particle—so great, indeed, that it gives to this bubble the very power of an India-rubber ball; for you see, if I introduce one end of this glass tube into the bubble, that it has the power of contracting so powerfully as to force enough air through the tube to blow out a light (*fig. 22*)—the light is blown out. And look! see how the bubble is disappearing—see how it is getting smaller and smaller.

There are twenty other experiments I might show you to illustrate this power of cohesion of the particles of liquids. For instance, what would you propose to me if, having lost the stopper out of this alcohol bottle, I should want to close it speedily with something near at

hand. Well, a bit of paper would not do, a piece of linen cloth would, or some cotton wool which I have here. I will tuck it into the neck of the alcohol bottle you see, when I turn it upside down, the perfectly well stoppered so far as the alcohol concerned; the air can pass through, but alcohol can not. And if I were to take this vessel this plan would do equally well, formerly times they used to send us oil from in flasks stoppered only with cotton wool, the present time the cotton is put in after the oil has arrived here, but formerly it used to be sent so stoppered). Now if it were not for

Fig. 12.

Fig. 13.



particles of liquid cohering together, this alcohol would run out; and if I had time I have shown you a vessel with the top, bottom and sides altogether formed like a sieve, yet it would hold water, owing to this co-

You have now seen that the solid water can become fluid by the addition of heat, owing to this lessening the attractive force between its particles, and yet you see that there is a good deal of attractive force remaining behind. I want now to take you another step beyond. We saw that if we continued applying heat to the water (as indeed happened with our piece of ice here), that we did at last break up that attraction which holds the liquid together, and I am about to take some ether (any other liquid would do, but ether makes a better experiment for my purpose) in order to illustrate what will happen when this cohesion is broken up. Now this liquid ether, if exposed to a very low temperature, will become a solid; but if we apply heat to it, it becomes vapor; and I want to show you the enormous bulk of the substance in this new form: when we make ice into water, we lessen its bulk; but when we convert water into steam, we increase it to an enormous extent. You see it is very clear that as I apply heat to the liquid I diminish its attraction of cohesion: it is now boiling, and I will set fire to the vapor, so that you may be enabled to judge of the

space occupied by the ether in this firm state of its fibres; and you now see what a massy body time I get from that small amount of ether below. The heat from the lamp is now being consumed, not in making ether any warmer, but in converting it into gas; and if I desired to catch this vapour as it rises, as I could without much difficulty, I should have to do the same as if I were to convert steam into water and water is in either case it would be necessary to diminish the attraction of the particles by cold or vice versa. So largely is the bulk occupied by particles increased by giving them this ethereal attraction, that if I were to take a cubic inch of water a cubic inch in bulk (a *fig.* 37), I could produce a volume of steam of that size, or nearly a cubic foot, so that the attraction of cohesion is diminished, and yet it still remains water. You can now imagine the consequences which are due to the change in volume by heat—the magnitude of steam and the tremendous expansion which are sometimes produced by this water. I want you now to see another

ment, which will perhaps give you a better illustration of the bulk occupied by a body when in the state of vapor. Here is a substance which we call iodine, and I am about to submit this solid body to the same kind of condition as regards heat that I did the water and the ether [putting a few grains of iodine into a hot glass globe, which immediately became filled with the violet vapor], and you see the same kind of change produced. Moreover, it gives us the opportunity of observing how beautiful is the violet-colored vapor from this black substance, or rather the mixture of the vapor with air (for I would not wish you to understand that this globe is entirely filled with the vapor of iodine).

If I had taken mercury and converted it into vapor (as I could easily do), I should have a perfectly colorless vapor; for you must understand this about vapors, that bodies in what we call the vaporous or the gaseous state are always perfectly transparent, never cloudy or smoky; they are, however, often colored, and we can frequently have colored vapors or gases produced by colorless particles themselves mix-

out producing water; and it is curious to think how often you must have made the experiment of combining oxygen and hydrogen to form water without knowing it. Take a candle, for instance, and a clean silver spoon (or a piece of clean tin will do), and, if you hold it over the flame, you immediately cover it with dew—not a smoke—which presently evaporates. This, perhaps, will serve to show it better. Mr. Anderson will put a candle under that jar, and you will see how soon the water is produced (*fig. 30*).

Fig. 30.



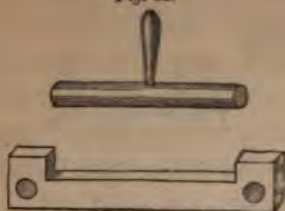
Look at that dimness on the sides of the glass, which will soon produce drops, and trickle down into the plate. Well, that dimness and these drops are *water*, formed by the union of the oxygen of the air with the hydrogen existing in the wax of which that candle is formed.

And now, having brought you, in the first place, to the consideration of chemical attraction, I must enlarge your ideas so as to include all substances which have this attraction for each other; for it changes the character of bodies, and alters them in this way and that way in the most extraordinary manner, and produces other phenomena wonderful to think about. Here is some chlorate of potash, and there some sulphuret of antimony.⁽¹⁷⁾ We will mix these two different sets of particles together, and I want to show you, in a general sort of way, some of the phenomena which take place when we make different particles act together. Now I can make these bodies act upon each other in several ways. In this case I am going to apply heat to the mixture; but if I were to give a blow with a hammer, the same result would follow. [A lighted match was brought to the mixture, which immediately exploded with a sudden flash, evolving a dense white smoke.] There you see the result of the action of chemical affinity overcoming the attraction of cohesion of the particles. Again, here is a little sugar⁽¹⁸⁾, quite a different substance from

forcibly pressed down, when a flame, due to combustion of the ether, was visible in the upper part of the syringe.] All we want is to get a little ether in vapor, and give fresh air some time, and so we may go on again and again, getting heat enough by the compression of the air to fire the ether-vapor.

This, then, I think, will be sufficient, accompanied with all you have previously seen, to show you how we procure heat. And now to show the effects of this power. We need not consider many of them on the present occasion, because, when you have seen its power of changing ice into water and water into steam, you have seen the two principal results of the application of heat. I want you now to see how it expands all bodies—all bodies but one, and that under limited circumstances. Mr. Anderson will hold a lamp under that retort, and you will see, the moment he does so, that the air will issue abundantly from the neck which is under water, because the heat which he applies to the air causes it to expand. And here is a brass rod (*fig. 32*) which goes through that hole, and fits also accurately into this gauge;

Fig. 32.



but if I make it warm with this spirit lamp, it will only go in the gauge or through the hole with difficulty; and if I were to put it into boiling water it would not go through at all. Again, as soon as the heat escapes from bodies, they collapse: see how the air is contracting in the vessel now that Mr. Anderson has taken away his lamp; the stem of it is filling with water. Notice too, now, that although I can not get the tube through this hole or into the gauge, the moment I cool it, by dipping it into water, it goes through with perfect facility, so that we have a perfect proof of this power of heat to contract and expand bodies.

at present; you see clearly there are two kinds of electricities which may be obtained by rubbing shellac with flannel or glass with silk.

Now there are some curious bodies in nature (of which I have two specimens on the table which are called *magnets* or *loadstones*; ores of iron, of which there is a great deal sent from Sweden. They have the attraction of gravitation, and attraction of cohesion, and certain chemical attraction; but they also have a great attractive power, for this little key is held by this stone. Now that is not chemical attraction; it is not the attraction of chemical affinity, or of aggregation of particles, or of cohesion, or of electricity (for it will not attract the ball if I bring it near it), but it is a separate and dual attraction, and, what is more, one which is not readily removed from the substance, for it has existed in it for ages and ages in the bowels of the earth. Now we can make artificial magnets (you will see me to-morrow make artificial magnets of extraordinary power). And let us take one of these artificial magnets and examine it, and see where the power is in the mass, and whether it is a dual power. You see

it attracts these keys, two or three in succession, and it will attract a very large piece of iron. That, then, is a very different thing indeed to what you saw in the case of the shellac, for *that* only attracted a light ball, but here I have several ounces of iron held up. And if we come to examine this attraction a little more closely, we shall find it presents some other remarkable differences; first of all, one end of this bar (*fig. 37*) attracts this key, but the middle does not attract. It is not, then, the *whole* of the substance which attracts. If I place this little key in the middle it does not adhere; but if I place it *there*, a little nearer the end, it does, though feebly. Is it not, then, very curious to find that there is an attractive power at the extremities which is not in the middle—to have thus in one bar two places in which this force of attraction resides? If I take this bar and balance it carefully on a point, so that it will be free to move round, I can try what action this piece of iron has on it. Well, it attracts one end, and it also attracts the other end, just as you saw the shellac and the glass did, with the exception of its not attracting in the middle. But if now,

Fig. 37.



Fig. 38.



instead of a piece of iron, I take a *magnet*, and examine it in a similar way, you see that one of its ends *repels* the suspended magnet; the force, then, is no longer attraction, but repulsion; but, if I take the other end of the magnet and bring it near, it shows attraction again.

You will see this better, perhaps, by another kind of experiment. Here (*fig. 38*) is a little magnet, and I have colored the ends differently, so that you may distinguish one from the other. Now this end (s) of the magnet (*fig. 37*) attracts the *uncolored* of the little magnet. You see it pulls toward it with great power; and, as I carry it round, the uncolored end still follows. But now, if I gradually bring the middle of the bar magnet opposite the uncolored end of the needle, it has no effect upon it, either of attraction or repulsion, until, as I come to the opposite extremity (N), you see that it is the *colored*

end of the needle which is pulled toward it. We are now, therefore, dealing with two kinds of power, attracting different ends of the magnet—a double power, already existing in these bodies, which takes up the form of attraction and repulsion. And now, when I put up this label with the word MAGNETISM, you will understand that it is to express this double power,

Now with this loadstone you may make magnets artificially. Here is an artificial magnet (*fig. 39*) in which both ends have been brought

Fig. 39.

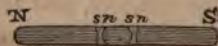


together in order to increase the attraction. This mass will lift that lump of iron, and, what is more, by placing this *keeper*, as it is called, on the top of the magnet, and taking hold of the handle, it will adhere sufficiently strongly

to allow itself to be lifted up, so wonderful is its power of attraction. If you take a needle, and just draw one of its ends along one extremity of the magnet, and then draw the other end along the other extremity, and then gently place it on the surface of some water (the needle will generally float on the surface, owing to the slight greasiness communicated to it by the fingers), you will be able to get all the phenomena of attraction and repulsion by bringing another magnetized needle near to it.

I want you now to observe that, although I have shown you in these magnets that this double power becomes evident principally at the extremities, yet the *whole* of the magnet is concerned in giving the power. That will at first seem rather strange; and I must therefore show you an experiment to prove that this is not an accidental matter, but that the whole of the mass is really concerned in this force, just as in falling the whole of the mass is acted upon by the force of gravitation. I have here (*fig. 40*)

Fig. 40.



a steel bar, and I am going to make it a magnet by rubbing it on the large magnet (*fig. 39*). I have now made the two ends magnetic in opposite ways. I do not at present know one from the other, but we can soon find out. You see, when I bring it near our magnetic needle (*fig. 38*), one end repels and the other attracts; and the middle will neither attract nor repel—it *can not*, because it is *half way between the two ends*. But now, if I break out that piece (*n, s*), and then examine it, see how strongly one end (*n*) pulls at this end (*s*, *fig. 38*), and how it repels the other end (*N*). And so it can be shown that every part of the magnet contains this power of attraction and repulsion, but that the power is only rendered evident at the end of the mass. You will understand all this in a little while; but what you have now to consider is that every part of this steel is in itself a magnet. Here is a little fragment which I have broken out of the very centre of the bar, and you will still see that one end is attractive and the other is repulsive. Now is not this power a most wonderful thing? And very strange, the means of taking it from one substance and

this subject too much, but if I take a piece of metal and bring it against the knob at the top and the metallic coating at the bottom, you will see the electricity passing through the air as a brilliant spark. It takes no sensible time to pass through this; and if I were to take a long metallic wire, no matter what the length, at least as far as we are concerned, and if I make one end of it touch the outside, and the other touch the knob at the top, see how the electricity passes! it has flashed instantaneously through the whole length of this wire. Is not this different from the transmission of heat through this copper bar (*fig. 42*), which has taken a quarter of an hour or more to reach the first ball?

Here is another experiment for the purpose of showing the conductibility of this power through some bodies and not through others. Why do I have this arrangement made of brass? [pointing to the brass work of the electrical machine, *fig. 41*]. Because it conducts electricity. And why do I have these columns made of glass? Because they obstruct the passage of electricity. And why do I put that pa-

ELECTRICAL REPULSION.

per tassel (*fig. 43*) at the top of the pole,
a glass rod, and connect it with this machi

Fig. 43.



means of a wire? You see at once that as
as the handle of the machine is turned, the
tricity which is evolved travels along this
and up the wooden rod, and goes to the

LECTURE VI.

THE CORRELATION OF THE PHYSICAL FORCES.

WE have frequently seen, during the course of these lectures, that one of those powers or forces of matter, of which I have written the names on that board, has produced results which are due to the action of some other force. Thus you have seen the force of electricity acting in other ways than in attracting; you have also seen it combine matters together or disunite them by means of its action on the chemical force; and in this case, therefore, you have an instance in which these two powers are related. But we have other and deeper relations than these; we have not merely to see how it is that one power affects another—how the force of heat affects chemical affinity, and so forth, but we must try and comprehend what relation they bear to each other, and how these powers may be changed one into the other; and it will to-day require all my care, and your care too, to

make this clear to your minds. I shall be obliged to confine myself to one or two instances, because to take in the whole extent of this mutual relation and conversion of forces would surpass the human intellect.

In the first place, then, here is a piece of fine zinc foil, and if I cut it into narrow strips and apply to it the power of heat, admitting the contact of air at the same time, you will find that it burns; and then, seeing that it burns, you will be prepared to say that there is chemical action taking place. You see all I have to do is to hold the piece of zinc at the side of the flame, so as to let it get heated, and yet to allow the air which is flowing into the flame from all sides to have access to it; there is the piece of zinc burning just like a piece of wood, only brighter. A part of the zinc is going up into the air in the form of that white smoke, and part is falling down on to the table. This, then, is the action of chemical affinity exerted between the zinc and the oxygen of the air. I will show you what a curious kind of affinity this is by an experiment which is rather striking when seen for the first time. I have here

more effective arrangement. Instead of having a machine which we are obliged to turn a long time together, we have here a *chemical* *cell* which sends forth the spark; and it is wonderful and beautiful to see how this spark is carried about through these wires. I want to perceive, if possible, that this very spark is the heat it produces (for there is heat) is neither more nor less than the chemical force of the zinc—its *very* force carried along wire and conveyed to this place. I am about to take a portion of the zinc and burn it in oxygen for the sake of showing you the kind of heat produced by the actual combustion in oxygen gas of some of this metal. [A tassel of zinc foil was ignited at a spirit lamp and introduced into a jar of oxygen, when it burnt with a brilliant light.] That shows you what the actual heat is when we come to consider it in its effect and power. And the zinc is being burnt by the battery behind me at a much more rapid rate than you see in that jar, because there it is there dissolving and *burning*, and producing here this great electric light. That very power which in that jar you saw evolved

the actual combustion of the zinc in oxygen, is carried along these wires and made evident here; and you may, if you please, consider that the zinc is burning in those cells, and that *this* is the light of that burning [bringing the two poles in contact and showing the electric light]; and we might so arrange our apparatus as to show that the amounts of power evolved in either case are identical. Having thus obtained power over the chemical force, how wonderfully we are able to convey it from place to place! When we use gunpowder for explosive purposes, we can send into the mine chemical affinity by means of this electricity; not having provided fire beforehand, we can send it in at the moment we require it. Now here (*fig. 47*) is a vessel containing two charcoal points, and I bring it forward as an illustration of the wonderful power of conveying this force from place to place. I have merely to connect these by means of wires to the opposite ends of the battery, and bring the points in contact. See what an exhibition of force we have! We have exhausted the air so that the charcoal can not burn, and therefore the light you see is really

ends of the battery, and which it is that possesses this peculiar action. You see it is the one on my right hand which has the power of

Fig. 91.



destroying the blue, for the portion on that side is thoroughly bleached, while nothing has apparently occurred on the other side. I say *apparently*, for you must not imagine that because you can not perceive any action none has taken place.

Here we have another instance of chemical action. I take these platinum plates again and immerse them in this solution of copper, from which we formerly precipitated some of the metal, when the platinum and zinc were both put in it together. You see that these two platinum plates have no chemical action of any kind; they might remain in the solution as long as I liked, without having any power of themselves to reduce the copper; but the mo-

CHEMICAL ACTION OF THE BATTERY 161

ment I bring the two poles of the battery in contact with them the chemical action which is there transformed into electricity and which along the wires again becomes chemical action at the two platinum poles and now we shall have the power appearing on the left-hand side, and throwing down the copper in the metallic state on the platinum plate: and in this way I might give you many instances of the extraordinary way in which this chemical action or electricity may be carried about. That strange nugget of gold of which there is a model in the other room, and which has an interest of its own in the natural history of gold, and which came from Ballarat, and was worth £8000 or £9000 when it was melted down last November, was brought together in the bowels of the earth, perhaps ages and ages ago, by some such power as this. And there is also another beautiful result dependent upon chemical affinity in that fine lead-tree⁽²⁴⁾, the lead growing and growing by virtue of this power. The lead and the zinc are combined together in a little voltaic arrangement in a manner far more important than the powerful one you now

if I were to examine the other end I should find that it was a magnet. See what power it

Fig. 54



must have to support not only these nails, but all those lumps of iron hanging on to the end. What, then, can surpass these evidences of the change of chemical force into electricity, and electricity into magnetism? I might show you many other experiments whereby I could obtain electricity and chemical action, heat and light from a magnet, but what more need I show you to prove the universal correlation of the physical forces of matter, and their mutual conversion one into another?

And now let us give place as juveniles to the respect we owe to our elders, and for a

time let me address myself to those of our seniors who have honored me with their presence during these lectures. I wish to claim this moment for the purpose of tendering our thanks to them, and my thanks to you all for the way in which you have borne the inconvenience that I at first subjected you to. I hope that the insight which you have here gained into some of the laws by which the universe is governed, may be the occasion of some among you turning your attention to these subjects; for what study is there more fitted to the mind of man than that of the physical sciences? And what is there more capable of giving him an insight into the actions of those laws, a knowledge of which gives interest to the most trifling phenomenon of nature, and makes the observing student find

“Tongues in trees, books in the running brooks,
Sermons in stones, and good in every thing?”

02 -

by fogs, or distance, or other circumstance, there arose the attempt to make larger lights by means of fires; and after that there was introduced a very important refinement in the mode of dealing with the light, namely, the principle of reflection; for understand this (which is now known by all, and not known by many who should know it), that when we take a source of light—a single candle, for instance, giving off any quantity of light, we can by no means increase that light; we can make arrangements around and about the light, as you see here, but we can by no means *increase the quantity of light*. The utmost I can do is to *direct* the light which the lamp gives me, by taking a certain portion of the rays going off on one side and reflecting them on to the course of the rays which issue in the opposite direction. First of all, let us consider how we may gather in the rays of light which pass off from this candle. You will easily see that if I could take the half rays on the one side, and could send them, by any contrivance, over to the other side, I should gain an advantage in light on the side to which I directed them. This is effected in a beautiful

manner by the parabolic mirror, by means of which I gather all that portion of the rays which are included in it—upward, downward, sideways, any where within its sphere of action, they are all picked up and sent forward. You thus see what a beautiful and important invention is that of the parabolic reflector for throwing forward the rays of light.

Before I go farther into the subject of reflection, let me point out a farther mode of dealing with the direction of the light. For instance, here is a candle, and I can employ the principle of *refraction* to bend and direct the rays of light, and if I want to increase the light in any one direction, I must either take a reflector or use the principle of refraction. I will place this lens (*fig. 56*) in front of the can-

Fig. 56.



dle, and you will easily see that by its means I can throw on to that sheet of paper a great light; that is to say, that instead of the light

being thrown all about, it is *refracted* and concentrated on to that paper; so here I have another means of bending the light and sending it in one direction; and you see above a still better arrangement for the same purpose—one which comes up to the maximum, I may say, of the ability of directing light by this means. You are aware that without that arrangement of glass the light would be dispersed in all directions, but the lens being there, all the light which passes through it is thrown into parallel beams and cast horizontally along. There is, consequently, no loss of light; the beam goes forward of the same dimensions, and will consequently continue to go forward for five or ten miles, or so long as the imperfection of the atmosphere does not absorb it. And see! what a glorious power that is, to be able to convert what was just now darkness on that paper into brilliant light!

Whenever we have refraction of this sort, we are liable to an evil consequent upon the necessary imperfections in the form of the lens; and Dr. Tyndall will take this lens, and will show you, even in this small and perfect apparatus,

what is the evil of spherical aberration with which we have to fight. This can be illustrated by means of the electric lamp. If you look at the screen, you will see produced, by means of this lens, a figure of the coal points. This image is produced by the rays which pass through the *middle* of the lens, a piece of card, with a hole in the centre, being placed in front; but if, keeping the rest of the apparatus in the same position, I change this card for another piece which will only allow the rays to pass through the *edge* of the lens, you observe how inferior the image will be. In order to get it distinct, I have to bring the screen much nearer the lamp; and so, if I take away the card altogether, and allow the light to pass through all parts of the lens, we can not get a perfect image, because the different parts of the lens are not able to act together. This spherical aberration is, therefore, what we try to avoid by building up compound lenses in the manner here shown (*fig. 58*). Look at this beautiful apparatus; is it not a most charming piece of workmanship? Buffon first, and Fresnel afterward, built up these kind of lenses, ring

cording to the purposes for which they are required; but suppose we want more effect than is produced by these means, how are we to get more light? Here comes the difficulty. We can not get more light, because we are limited by the condition of the burner. In any of these cases, if the spreading of the ray, or *divergence*, as it is called, is not restrained, it soon fails from weakness; and if it does not diverge at all, it makes the light so small that perhaps only one in a hundred can see it at the same time. The South Foreland light-house is, I think, 300 or 400 feet above the level of the sea, and therefore it is necessary to have a certain divergence of the beam of light in order that it may shine along the sea to the horizon. I have drawn here two wedges: one has an angle of 15° , and shows you the manner in which the light opens out from this reflector, seen at the distance of half a mile or more; the other wedge has an angle of 6° , which is the beautiful angle of Fresnel. When the angle is less than 6° , the mariner is not quite sure that he will see the light—he may be beneath or above it; and in practice it is found that we can not have a larger

angle than 15° , or a less one than 6° . In order, therefore, to get more light, we must have more combustion, more cotton, more oil; but already there are in that lamp four wicks, put in concentric rings one within the other, and we can not increase them much more, owing to the divergence which would be caused by an increase in the size of the light; the more the divergence, the more the light is diffused and lost. We are therefore restrained by the condition of the light and the apparatus to a certain sized lamp. At Teignmouth some of the revolving lights have ten lamps and reflectors, all throwing their light forward at once. But even with ten lamps and reflectors we do not get sufficient light; and we want, therefore, a means of getting a light more intense than a candle in the space of a candle—not merely an accumulation of candle upon candle, but a concentration into the space of a candle of a greater amount of light, and it is here that the electric light comes to be of so much value.

Let me now show you what are the properties of that light which make it useful for lighthouse illumination, and which has been brought

to a practical condition by the energy and constancy of Professor Holmes. I will first of all show you the image of the charcoal points on the screen, and draw your attention to the spot where the light is produced. There are the coal points. The two carbons are brought within a certain distance; the electricity is being urged across by the voltaic battery, and the coal points are brought into an intense state of ignition. You will observe that the light is essentially given by the carbons; you see that one is much more luminous than the other, and that is the end which principally forms the spark; the other does not shine so much; and there is a space between the two which, although not very luminous, is most important to the production of the light. Dr. Tyndall will help me in showing you that a blast of wind will blow out that light; the electric light can in fact be blown out easier than a candle. We have the power of getting our light where we please. If I cause the electricity to pass between carbon and mercury, I get a most intense and beautiful light, most of it being given off from the portion of the mercury between the liquid and

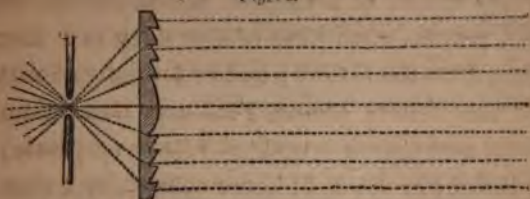
the solid pole. I can show you that the light is sometimes produced by the vapor between the two poles better if I take silver than when I use mercury. Here is the carbon pole, there is the silver, and there is the beautiful green light which comes from the intervening portions. Now that light is more easily blown out than the common lamp, the slightest puff of wind being sufficient to extinguish it, as you will see if Dr. Tyndall breathes upon it.

You see, therefore, how we are able, by using this electric spark, to get, first of all, the light into a very small space. That oil lamp has a burner $3\frac{3}{4}$ inches in diameter; compare the size of the flame with the space occupied by this electric light. Next compare the intensity of this light with any other; if I take this candle and place it by the side, I actually seem to put out the candle. We are thus able to get a light which, while it surpasses all others in brilliancy, is at the same time not too large, for I might put this light into an apparatus not larger than a hat, and yet I could count upon the rays being useful. Moreover, when such large burners are used in a lantern, we have to

consider whether the bars of the window do not interfere to throw a shadow or otherwise; but with this light there will be no difficulty of that sort, as a single small speculum no larger than a hat will send it in any direction we please; and it is wonderful what advantages, by reason of its small bulk, we have in the consideration of the different kinds of apparatus required, reflecting or refracting, irrespective of other reasons for using the electric light. And it is these kind of things which make us decide most earnestly and carefully in favor of the electric light.

* I am going to show you the effect that will take place with that large lens when we throw the oil lamp out of action, and put the electric light into use. It is astonishing to find how little the eye can compare the relative intensities of two lights. Look at that screen, and try to recollect the amount of light thrown upon it from the $3\frac{3}{4}$ inch lamp of Fresnel, and now, when we shift the lens sideways, look at the glorious light arising from that small carbon point (*fig. 58*); see how beautifully it shines in the focus of that lens, and throws the rays for-

Fig. 18.



ward. At present the electric light is put at just the same distance as the oil light, and therefore, being in the focus of the lens, we have parallel rays which are thrown forward in a perfectly straight line, as you will see by comparing the size of the lens with that of the light thrown on the screen. You will now see how far we can affect this beam of light by increasing or diminishing the distance of the lamp. We are able, by a small adjustment, to get a beam of a large or small angle, and observe what power I have now over it; for if I want to increase the degrees of divergence, I am limited by the power of light in the case of the oil lamp, but with the electric light I can make it spread over any width of the horizon by this simple adjustment. These, then, are some of the reasons which make it desirable to employ the electric light.

By means of a magnet, and of motion, we can get the same kind of electricity as I have here from the battery; and under the authority of the Trinity House, Professor Holmes has been occupied in introducing the magneto-electric light in the light-house at the South Foreland; for the voltaic battery has been tried under every conceivable circumstance, and I take the liberty of saying it has hitherto proved a decided failure. Here, however, is an instrument wrought only by mechanical motion. The moment we give motion to this soft iron in front of the magnet, we get a spark. It is true, in this apparatus it is very small, but it is sufficient for you to judge of its character. It is the *magneto-electric* light, and an instrument has been constructed, as there shown (*fig. 59*), which represents a number of magnets placed radially upon a wheel—three wheels of magnets and two sets of helices. When the machine, which is worked by a two-horse power engine, is properly set in motion, and the different currents are all brought together, and thrown by Professor Holmes up into the lantern, we have a light equal to the one we have been using this

Fig. 50.



evening. For the last six months the South Foreland has been shining by means of this electric light—beyond all comparison better than its former light. It has shone into France, and has been seen there and taken notice of by the authorities, who work with beautiful accord with us in all these matters. Never for once during six months has it failed in doing its duty; never once—more than was expected by the inventor. It has shone forth with its own peculiar character, and this even with the old

apparatus, for as yet no attempt has been made to construct special reflectors or refractors for it, because it is not yet established. I will not tell you that the problem of employing the magneto-electric spark for light-house illumination is quite solved yet, although I desire it should be established most earnestly (for I regard this magnetic spark as one of my own offspring). The thing is not yet decidedly accomplished, and what the considerations of expense and other matters may be I can not tell. I am only here to tell you, as a philosopher, how far the results have been carried; but I do hope that the authorities will find it a proper thing to carry out in full. If it can not be introduced at all the light-houses, if it can only be used at one, why really it will be an honor to the nation which can originate such an improvement as this—one which must of necessity be followed by other nations.

You may ask, What is the use of this bright light? It would not be useful to us were it not for the constant changes which are taking place in the atmosphere, which is never pure. Even when we can see the stars clearly on a

bright night it is not a pure atmosphere. The light of a light-house, more than any other, is liable to be dimmed by vapors and fogs, and where we most want this great power is not in the finest condition of the atmosphere, but when the mariner is in danger, when the sleet and rain are falling, and the fogs arise, and the winds are blowing, and he is nearing coasts where the water is shallow and abounds with rocks: then is his time of danger, when he most wants this light. I am going to show you how, by means of a little steam, I can completely obscure this glorious sun, this electric light which you see. The cloud now obscuring the light on the screen is only such a cloud as you see when sitting in a train on a fine summer's day; you may observe that the vapor, passing out of the funnel, casts as deep a shadow on the ground as the black funnel; the very sun itself is extinguished by the steam from the funnel, so that it can not give any light; and the sun itself, if set in the light-house, would not be able to penetrate such a vapor.

Now the haze of this cloud of steam is just

cork of a bottle and fasten a plate of zinc round them just as they issue from the cork, so that the zinc may be in contact with every one of the wires. Make the wires to diverge so as to form a sort of cone and, having filled the bottle quite full of a solution of sugar of lead, insert the wires and cork and seal it down, so as to perfectly exclude the air. In a short time the metallic lead will begin to crystallize around the divergent wires and form a beautiful object.

THE END.





AUG 21 1828

